TechData Sheet

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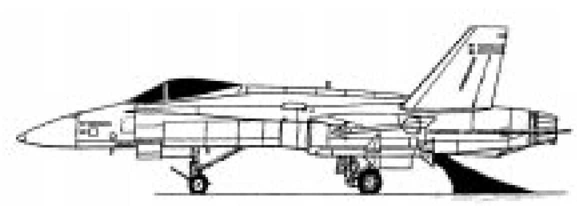
A CONCRETE SOLUTION TO THE F/A-18 PARKING APRON PROBLEM

F/A-18 aircraft will damage your concrete pavements! Portland cement concrete pavements at locations where F/A-18 aircraft are based are either already damaged, or will be damaged soon. The damage occurs in the form of “scaling” of the top ¼ to ½ inch of the pavement surface. Pavement fragments from these surface scales have the potential to produce FOD (foreign object damage) to aircraft engines.



Damaged Area

Figure 1. F/A-18 Exhaust Profile

The high temperature exhaust gases from the Auxiliary Power Unit (APU) of the F/A-18 aircraft coupled with spilled fluids from this aircraft damage ordinary Portland cement concrete airfield pavements (Figure 1). The damage occurs progressively to the pavement surface due to repeated thermal cycling and chemical reaction of the spilled aircraft fluids with the cement paste. Pavement damage from the F/A-18 has been observed in various locations as shown in Table 1.

Table 1. APU Pavement Damage

Air Station	Time to Initial Scaling
NAS Fallon, NV	8 to 24 months
MCAS El Toro, CA	12 months
MCAS Iwakuni, Japan	18 months
NAS Cecil Field, FL	< 21 months
MCAS Beaufort, SC	< 2-1/2 years
NAS Point Mugu, CA	1-1/2 to 2-1/2 years
NAS North Island, CA	2 to 3 years
NAS Lemoore, CA	3 to 5 years

Investigations were conducted in an attempt to assess the temperatures on the pavement surface over time, due to exposure to the F/A-18 APU exhaust. The aircraft manufacturer reports F/A-18 APU maximum deck temperatures on the order of 328ºF to 350ºF. Tests conducted by the Naval Air Propulsion Center (NAPC) and Naval Air Warfare Center (NAWC) corroborated these temperature values. This information was used in conducting analyses and laboratory tests on candidate F/A-18 APU resistant pavement systems.

The Office of Naval Research sponsored an experimental investigation by the Naval Facilities Engineering Service Center (NFESC) to develop candidate pavement systems that would be resistant to the thermal/blast effects from the F/A-18 APU exhaust and the spilled fluids from this aircraft. Simulated high temperature exposure tests were conducted on candidate pavement systems in NFESC's High Temperature Jet Exhaust Simulation Facility. This facility, which operates with natural gas, is capable of simulating the heat flux of various jet engine exhausts, from the F/A-18 APU to the V-22 and AV-8B aircraft main engines (Figure 2).

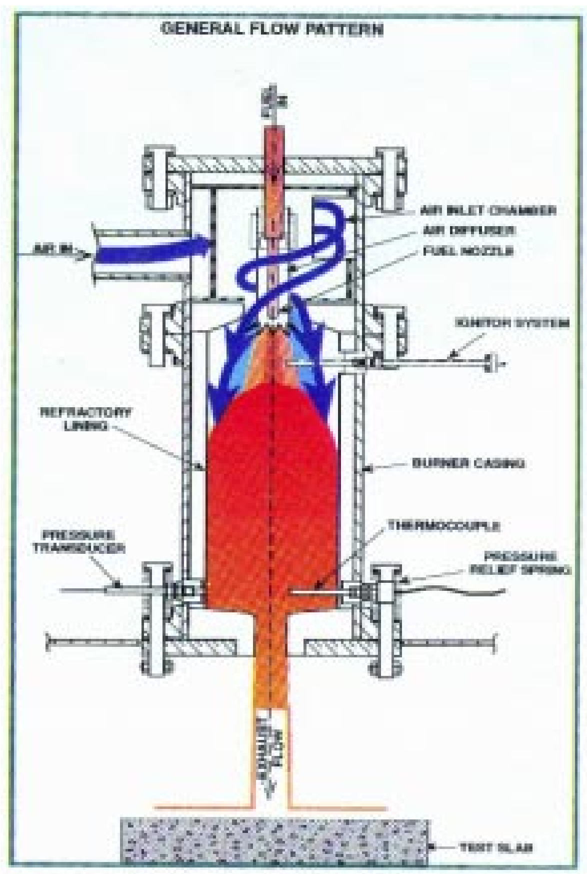


Figure 2. Schematic of NFESC High Temperature Jet Engine Simulation Facility

Three factors are considered to be the major contributing causes of the failure of pavements subjected to the F/A-18 APU exhaust. These factors are: thermal fatigue, vapor pressure, and chemical degradation. Thermal fatigue is evidenced by the fact that failures have occurred without the presence of oils or fuels, and that scaling failure planes have been observed to fracture aggregates. Vapor pressure could be detrimental in the case of saturated or partially saturated pores where the water vapor pressure cannot be relieved fast enough during the heating phase. Chemical degradation results in a significant loss of strength, up to 50% in some cases, which accelerates the failure. Chemical degradation by itself could result in raveling of the concrete but would not produce scaling. Chemical degradation alone could not reproduce the observed failures. In the experimental investigation, accurate simulation of the thermal fatigue was considered essential for proper reproduction of the failure mechanism. The experimental and numerical analyses were therefore focused on investigating thermal fatigue as a primary cause of failure. F/A-18 APU engine oil was also applied to the samples to evaluate the resulting strength degradation. Vapor pressure effects were studied under a separate program which concluded that their effect would be minor under F/A-18 APU imposed conditions.

The numerical analyses showed that the thermal stress gradient of the pavement surface would be reduced if the modulus of elasticity, coefficient of thermal expansion, and specific heat were lowered, and if the conductivity was increased. Structural lightweight aggregate concrete appeared to be a good candidate as its modulus of elasticity and coefficient of thermal expansion are significantly lower than for ordinary weight concrete. Mixes were designed and laboratory evaluation tests were conducted to determine the best aggregate and formulation. Performance data indicated that expanded shale fine and coarse aggregates would be the most suitable.

Various test specimens of candidate pavement formulations and ordinary Portland cement concrete controls were fabricated with the expanded shale aggregate system as well as ordinary concrete aggregates. These specimens were 24 inches in diameter and 6 inches thick. The cementing agents used were: (1) ordinary Portland cement, (2) magnesium ammonium phosphate, and (3) magnesium aluminum phosphate binder system. The aggregates used were: (1) expanded shale fine and coarse aggregate, (2) ASTM C33 fine aggregate and Size No. 57 coarse aggregate (standard Navy pavement) and, (3) ASTM C33 Size No. 8 aggregate. Three to four specimens of each formulation were fabricated.

Cyclic exposure tests of the specimens were conducted in the NFESC High Temperature Jet Exhaust Simulation Facility (Figure 3). The simulated jet was calibrated to replicate the heat flux from the F/A-18 APU exhaust on ordinary concrete pavements. That heat flux produces a concrete surface temperature of 325ºF after ten minutes of exposure. The thermal gradients present during the pavement heating are enhanced if the initial pavement temperature is lower. To recreate the most conservative scenario, the test slabs were cooled down to just above freezing (34ºF) before each exposure cycle.

Figure 3. NFESC High Temperature JES Facility Setup

Test specimens exposed to the simulated jet exhaust failed in two basic modes: scaling (Figure 4) and progressive internal and external damage. The Portland cement (PC) based specimens generally failed early in scaling, except for two specimens that were not contaminated with oil. Specimens with other types of binders (magnesium ammonium phosphate and magnesium aluminum phosphate) generally experienced progressive damage. Test results indicated that all lightweight PC concrete had a thermal cycling resistance (in presence of oil) 3.7 times higher than that of ordinary PC concrete. Elimination of the oil would itself further improve the results eight-fold, underlining the importance of the chemical degradation. An optimized mix using all-lightweight concrete with a neutral-pH cementitious agent was expected to mitigate both the thermal stresses and the chemical degradation. At the end of 351 cycles, specimens from this mix exhibited mostly hairline cracks and some exposed aggregates at the surface (Figure 5).

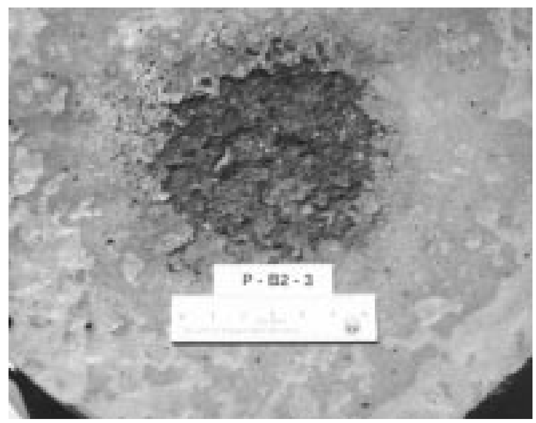


Figure 4. Standard Navy Airfield Portland Cement Concrete at Heat Cycle 50

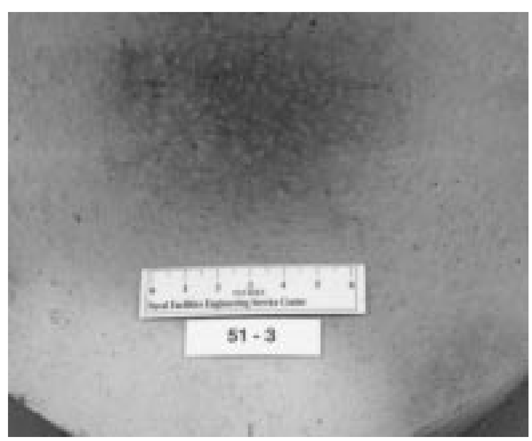


Figure 5. Magnesium Ammonium Phosphate Cement with 3/8-Inch Expanded Shale Aggregate at Cycle 351

Based on the analytical modeling and laboratory testing of candidate pavement systems under simulated F/A-18 APU jet exhaust conditions, several candidate pavement systems superior to standard Navy airfield pavements constructed with ordinary Portland cement were developed. The candidate systems were ranked as follows, from best to worst performer:

1. Magnesium ammonium phosphate cement with 3/8-inch expanded shale aggregate (least damaged, 15 times better than control).

2. Portland cement with expanded shale aggregate (performed 3.7 times better than control).

3. Magnesium ammonium phosphate cement with ASTM C33 Size No. 8 aggregate (cracked).

4. Magnesium aluminum phosphate binder system (very short set time, cracked and spalled).

5. Portland cement with ASTM C33 Size No. 57 aggregate (control airfield pavement).

In the experiments, it was also found that samples not subjected to the oil withstood significantly more heating cycles. Hence in the operational environment, minimizing and removing any spilled oils from existing pavement surfaces will also significantly extend the life of the pavement.

An analysis was made of the relative in-place replacement cost and performance of the top two candidate systems compared to the standard Navy airfield pavement concrete. Table 2 presents the results.

Although the top two candidate systems have high relative initial costs, their life-cycle costs promise to be approximately one-half that of the standard pavement. When potential for FOD is considered, the first candidate becomes even more attractive because scaling did not occur in the test specimens and it shows promise of lasting the longest before any repairs would be necessary.

Table 2. Cost Efficiency of Best Candidates

Candidate Pavement	In-Place Cost ($/yd^3)	Relative Cost	Relative Performance	Cost Efficiency
Magnesium ammonium phosphate cement with 3/8-inch expanded shale aggregate	1588	8.6	15.0	1.7
Portland cement with expanded shale aggregate	332	1.8	3.7	2.0
Standard airfield pavement	184	1.0	1.0	1.0

The saying goes: it works great in the laboratory but how about in the “real world” environment? That is the next step in the development of the candidate systems. If you are willing to host a field evaluation of the candidates, we would be delighted to hear from you!

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